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Power generation and renewable potential in China

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ABSTRACT

Due to long-term, coal-based electricity generation, China's power industry has produced not only heavy burdens on provincial coal supplies but has also caused serious environmental deterioration. This paper discusses the current status and future development trend of China's power generation. By using the Johansen co-integration test and the error correction model (ECM), the paper shows the existence of a synchronous increase between China's economy and its electricity production. Then, a GM(1,1) model is applied to predict China's economic production in 2015. By using that prediction, the ECM to estimate the related electricity generation. Next, based on the 2015 power generation prediction, this paper discusses the development trend of China's future power structure, especially in regard to renewable energy, and also provides an overview of the potential reserves and current development status of China's renewable power generation as well as the 12th Five-Year Plan (FYP), with suggestions for the future development of renewable energy. Last, a centralized combined dispatching policy, including trans-provincial and trans-regional power transmissions, is considered.

Contents

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1. Introduction

As one of the most important industries in an economy, power-generation affects the normal operation of society and the basic protection of people's lives. A fast-developing society requires strong support from the electricity sector. In the developing country of China, power installation has boomed in the past few years, along with a rapidly expanding economy. Since China's national reform and opening policy began in 1978, the synchronously increasing trend between the economy and electricity generation has been remarkable (Fig. 1). The rapid expansion in energy demand has resulted mainly from the extremely rapid growth of gross national product (GDP; a nearly 10% annual average growth for the past three decades) and the transformation of the economic structure toward exports and heavy industry, especially after China became a member of the World Trade Organization (WTO) in 2011 [1].

A long-term equilibrium relationship exists between the economy and electricity demand [2,3]. In China, the rapid growth of the economy has led to a sharp rise in power demand, which has given rise to mounting concerns regarding national energy security. China's electricity generation is largely from coal-based thermal power, which makes up more than 80% of the total national electricity generation [4]. With such a high proportion of thermal power generation, the large, coal-based energy structure in China has increased pressure on both coal production and environmental protection [5]. In addition, the unbalanced distribution of coal resources in China has sharply increased the cost of energy because of the long-distance coal transport that is required. More importantly, thermal power generation emits large quantities of greenhouse gases and toxic pollutants, mainly carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter. These toxic pollutants cause respiratory infections and cancer and can raise mortality and morbidity rates [6]. Currently, China's record on greenhouse gas emissions is becoming a concern not only for China but for the rest of the world as well [7].

To solve the rising energy requirements and the increase in serious environmental pollutants, an energy revolution is needed—namely, renewable energy. The Special Report on Renewable Energy Sources and Climate Change Mitigation 2011 of Intergovernmental Panel on Climate Change (IPCC 2011) states that renewable energies are an affordable and economically viable option for the electricity needs of people in developing countries [7]. Because of the damage caused by China's long-term, coal-based electricity generation, clean power generation is urgently required.

The potential of renewable energy in China is huge, but similarly, regarding coal, the distribution of resources is unbalanced. Specifically, approximately 70% of the total water resources are found in the southwest [8], and wind energy resources are centralized across the northern regions [9]. Solar energy is a rich resource, especially in Qinghai-Tibet Plateau, northern Gansu, northern Ningxia, and southern Xinjiang [10]. Compared to hydropower, both wind and solar power are more promising prospects because they have the strong support of government finance and policy. In its 12th FYP (2011–2015), The Chinese government strongly encourages the development of renewable power generation, especially hydropower, wind power, and photovoltaic (PV) power.

With the booming development trend of wind and PV power, renewable energy is likely to account for a significant share of the future power sector. However, in contrast to traditional fossil fuels, renewable energy sources do not produce a constant supply of energy. Therefore, when intermittent renewable power is integrated into a power grid, the availability of electricity may become inconsistent. One solution to this is the adoption of combined renewable – thermal scheduling, instead of the usual hydro – thermal scheduling. Thus, the mixed renewable-thermal coordination techniques are urgently required. Some works have been done in this area [11–13]. In renewable-thermal scheduling, the combined schedule includes two aspects: trans-provincial and trans-regional power transmission and smart grid development. Because each renewable power source has its own volatility and periodicity, a centralized schedule of combining thermal power with renewable power is needed so that when one power output decreases, another type of electricity generation can supplement for that loss. For this reason, the 12th FYP includes the projected building of several long-distance transmission lines to promote better power utility nationwide [14].

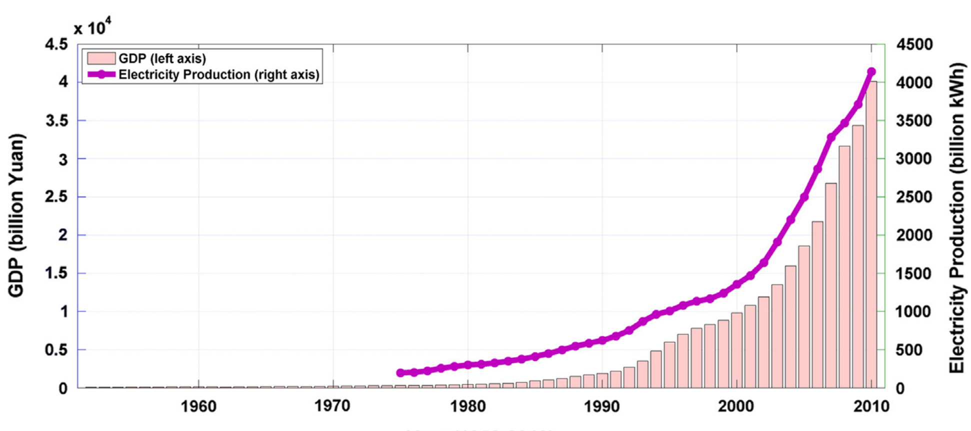

Fig. 1. The historical data of China's GDP and electricity production.
Resources: Ref. [15].

This paper focuses on China's current methods of power generation and the potential of renewable methods of power generation in 2015. Section 2 introduces China's current power generation and energy consumption levels. Section 3 analyzes the national renewable power potential, its current status, and its prospective development. By applying the Johansen co-integration test, result shows that there is a long-term equilibrium relationship between China's economy and electricity production. The following sections also show how an error correction model (ECM) can be used to describe that relationship. Finally, a grey model is applied to predict the national economy in 2015. Using that prediction, it shows how China's total electricity generation in 2015 can be estimated by the ECM; this estimation will be useful in our following discussions about China's electrical power structure.

This paper will also discusses combined renewable-thermal scheduling, including trans-provincial and trans-regional grid operations. Section 4 considers what is required to carry out government energy policies, and Section 5 discusses the current power generation in China and provides some suggestions about the future power structure. Finally, Section 6 provides a concluding summary of this paper. Renewable power generation is growing at a fast pace in China.

2. Current power generation in China

2.1. Equilibrium relationship between China's GDP and electricity production

When discussing the relationship between China's GDP and electricity production, two aspects must be considered: the long-term equilibrium relationship and the short-term fluctuation effect. The historical relationship of China's GDP (1952–2010) and electricity production (1975–2010) is displayed in Fig. 1. Before 1978, China experienced a long period of only slight GDP growth, mainly due to its backward social productivity and undeveloped scientific technology. Since China's reform and opening up in 1978, the national GDP has grown rapidly and continuously. Fig. 1 clearly shows a uniform growth trend between GDP and electricity production (related coefficient=0.993).

Table 1
The results of Augmented Dickey–Fuller test.

	t-Statistic	Test critical values			Probability
		1% Level	5% Level	10% Level	
GDP	3.56	−4.36	−3.40	−3.23	1.0000
EP	2.69	−4.30	−3.57	−3.22	1.0000
ln(GDP)	0.17	−3.66	−2.96	−2.62	0.9662
ln(EP)	1.94	−3.66	−2.96	−2.62	0.9997
D(ln(GDP))	−3.02	−3.66	−2.96	−2.62	0.0435
D(ln(EP))	−3.66	−4.28	−3.56	−3.22	0.0412

2.1.1. Johansen co-integration test

To determine whether there is a long-term equilibrium relationship between China's GDP and electricity production (EP), this section used data from 1975–2010. First, a series stationary test – Augmented Dickey–Fuller (ADF) test – is employed, which is a test for a unit root in a time series sample [16]. The ADF test is applied to the model

$$\Delta y_t = \gamma y_{t-1} + \sum_{i=1}^{p-1} \delta_i \Delta y_{t-i+1} + \varepsilon_t \tag{1}$$

where p is the lag order of the autoregressive process. The testing of a unit root is equivalent to the testing of $\gamma=0$, which is the null hypothesis of the ADF test. This indicates that the lag series y_{t-1} will provide no relevant information in predicting Δy_t. Further, the alternative hypothesis is $\gamma < 0$. The confidence level is set as $\alpha=0.05$ in this paper.

First, a series stationary test—the augmented Dickey–Fuller test is employed. Our null hypothesis was that each tested series had a unit root. For each series, $p=1.00$; that is, the probability of accepting the null hypothesis was 100%. Therefore, each series had a unit root and was non-stationary (Table 1).

Then, a logarithmic transformation for both the GDP and EP series is applied. There were two reasons for this: First, from the point of data processing, the logarithmic transformation can eliminate a portion of the heteroscedasticity, which affects model performance. Second, the difference of a variable's logarithm is approximately equal to the changing rate of that variable; the changing rate of an economic variable is usually stationary. Table 1 shows the stationary test results of logarithmic variables, ln(x) denotes the natural logarithm function and $D(x)$ denotes the first-order difference. For both the ln(GDP) and ln(EP) series, the null hypothesis was accepted ($p > .05$): each series had a unit root and

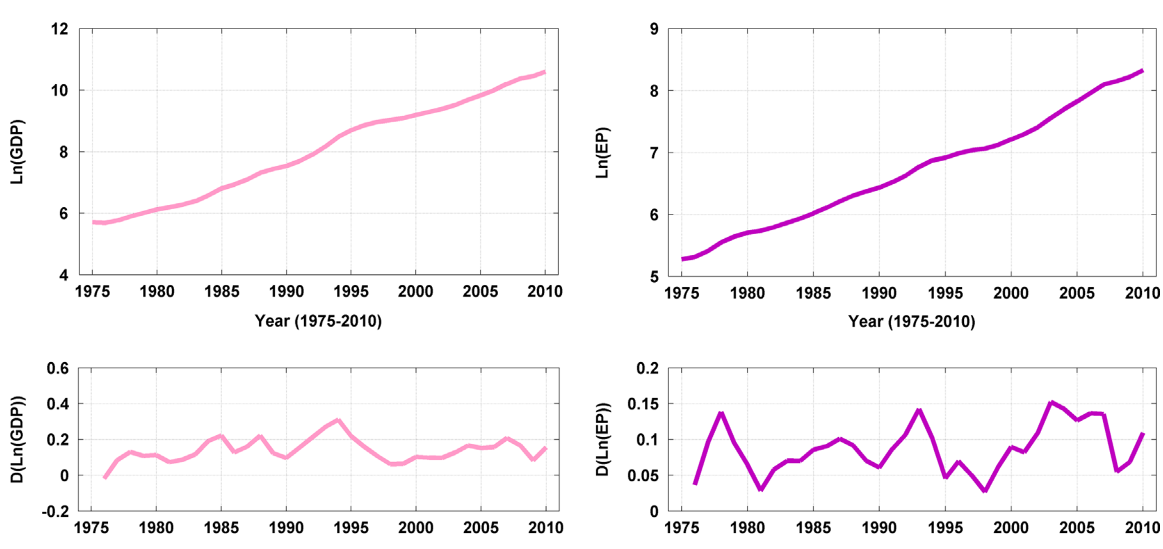

Fig. 2. Transformation of two data series.

Table 2
The results of Johansen co-integration test.

Hypothesized number of co-integration(s)	Eigenvalue	Trace statistic	0.05 Critical value	Probability
None [a]	0.37	18.49	12.32	0.0041
At most 1	0.07	2.61	4.13	0.1256
Hypothesized number of co-integration (s)	**Eigenvalue**	**Max-eigenvalue statistic**	**0.05 Critical value**	**Probability**
None [a]	0.37	15.88	11.22	0.0071
At most 1	0.07	2.61	4.13	0.1256

[a] Denotes rejection of the hypothesis at the 0.05 level.

Table 3
The model parameters of long-term equilibrium relationship.

		Coefficient	Standard error	*t*-Statistic	Probability
With no lag	α_0	2.14	0.10	21.67	0.0000
	α_1	0.57	0.01	46.95	0.0000
	R-squared	0.9848			
	Durbin–Watson statistic	0.12			
With first-order lagged	α_0	−0.06	0.11	−0.51	0.6109
	α_1	0.19	0.09	2.23	0.0329
	α_2	1.04	0.05	20.24	0.0000
	α_3	−0.21	0.08	−2.55	0.0161
	R-squared	0.9989			
	Durbin–Watson statistic	0.90			
With second-order lagged	α_0	0.07	0.09	0.77	0.4448
	α_1	0.30	0.10	3.12	0.0042
	α_2	1.53	0.14	10.53	0.0000
	α_3	−0.63	0.15	−4.06	0.0004
	α_4	−0.55	0.15	−3.60	0.0012
	α_5	0.35	0.08	4.20	0.0002
	R-squared	0.9994			
	Durbin–Watson statistic	2.01			
	Residual stationary test			−3.88	0.0004

Table 4
The short-term un-equilibrium parameters of the first-order lagged form.

	Coefficient	Standard error	*t*-Statistic	Probability
β_1	0.35	0.11	3.21	0.0032
β_2	0.93	0.16	5.78	0.0000
β_3	−0.33	0.11	−2.98	0.0058
$-\lambda$	−0.45	0.26	−1.70	0.0992
Durbin–Watson statistic	1.88			
Residual stationary test			−2.61	0.0108

was non-stationary. However, $p<.05$ for $D(\ln(\text{GDP}))$ and $D(\ln(\text{EP}))$, the null hypothesis was rejected: the difference for each series was stationary (Fig. 2). Therefore, both ln(GDP) and ln(EP) are first-order integration serial data, which is denoted as $I(1)$.

A co-integration relationship exists when the linear combination of two non-stationary time series, which are both *n*-order integration series ($n \geq 1$), is stationary. This section used the Johansen co-integration test (Table 2) to determine whether there was a co-integration relationship between the ln(GDP) and ln(EP) series. For both the trace test and max-eigenvalue test results, the hypothesis of no co-integration was rejected; that is, a co-integration relationship existed. Our results indicate that there is a long-term equilibrium relationship between China's GDP and EP.

2.1.2. ECM model

This section uses the ECM model to quantitatively describe the relationship between China's GDP and EP series. Next, the Engle–Granger two-step method [17–19] is applied to construct the ECM model.

- Step 1: Estimate the long-term equilibrium relationship.
  From Table 2, it can be known that there is a co-integration relationship between ln(GDP) and ln(EP). Assume that the long-term equilibrium relationship between these two series can be written as

$$\ln(\text{EP}_t) = \alpha_0 + \alpha_1 \ln(\text{GDP}_t) + \mu_t \tag{2}$$

where μ_t is stationary. The model parameter in Eq. (1) is estimated using the ordinary least squares (OLS) method. Table 3 lists the parameter estimations of Eq. (2). Considering that the Durbin-Watson (DW) value is 0.12, which is far away from 2, the residual series is auto-correlative. Therefore, the lagged items should be added into Eq. (2), written as

$$\begin{aligned}\ln(\text{EP}_t) = {} & \alpha_0 + \alpha_1 \ln(\text{GDP}_t) + \alpha_2 \ln(\text{EP}_{t-1}) + \alpha_3 \ln(\text{GDP}_{t-1}) \\ & + \alpha_4 \ln(\text{EP}_{t-2}) + \alpha_5 \ln(\text{GDP}_{t-2}) + \mu_t\end{aligned} \tag{3}$$

The results from Table 3 show that the DW value is 2.01 for the second-order lagged form; the auto-correlation of residual is eliminated. Furthermore, the ADF test is taken again. This result shows that the residual series does not have a unit root, but is stationary. Thus, the long-term equilibrium relationship can be written as

$$\begin{aligned}\ln(\text{EP}_t) = {} & 0.07 + 0.30 \times \ln(\text{GDP}_t) + 1.53 \times \ln(\text{EP}_{t-1}) - 0.63 \\ & \times \ln(\text{GDP}_{t-1}) - 0.55 \times \ln(\text{EP}_{t-2}) + 0.35 \times \ln(\text{GDP}_{t-2})\end{aligned} \tag{4}$$

and the error correction item can be defined as

$$ecm_t = \ln(\mathrm{EP}_t) - 0.07 - 0.03 \times \ln(\mathrm{GDP}_t) - 1.53 \times \ln(\mathrm{EP}_{t-1}) + 0.63 \times \ln(\mathrm{GDP}_{t-1}) + 0.55 \times \ln(\mathrm{EP}_{t-2}) - 0.35 \times \ln(\mathrm{GDP}_{t-2}) \quad (5)$$

- Step 2: Estimate the short-term un-equilibrium relationship. According to the Granger Representation Theorem [19], if the variables X and Y are co-integrated, their short-term un-equilibrium relationship can be represented by an error correction model, as

$$\Delta Y_t = lagged(\Delta Y_t,\ \Delta X_t) - \lambda \mu_{t-1} + \varepsilon_t \quad (6)$$

where μ_{t-1} is the deviation of long-term equilibrium at time $(t-1)$ and $\lambda (0<\lambda<1)$ is the short-term adjustment parameter. For the issue discussed in this paper, both $D(\ln(\mathrm{GDP}))$ and $D(\ln(\mathrm{EP}))$ are a $I(0)$ series. Thus, the right side of Eq. (6) can also include the item ΔX_t, which is a $I(0)$ series. Considering that the DW value should be close to 2, the first-order lagged form of Eq. (6) is adopted (Table 4 shows), as

$$\Delta \ln(\mathrm{EP}_t) = \beta_1 \Delta \ln(\mathrm{GDP}_t) + \beta_2 \Delta \ln(\mathrm{EP}_{t-1}) + \beta_3 \Delta \ln(\mathrm{GDP}_{t-1}) - \lambda \times ecm_{t-1} + \varepsilon_t \quad (7)$$

In Table 4, the DW statistic is calculated as 1.88. And the residual stationary test shows that the residual series does not have a unit root, but is stationary. Thus, the ECM model of China's GDP and EP can be written as

$$\Delta \ln(\mathrm{EP}_t) = 0.35 \times \Delta \ln(\mathrm{GDP}_t) + 0.93 \times \Delta \ln(\mathrm{EP}_{t-1}) - 0.33 \times \Delta \ln(\mathrm{GDP}_{t-1}) - 0.45 \times ecm_{t-1} \quad (8)$$

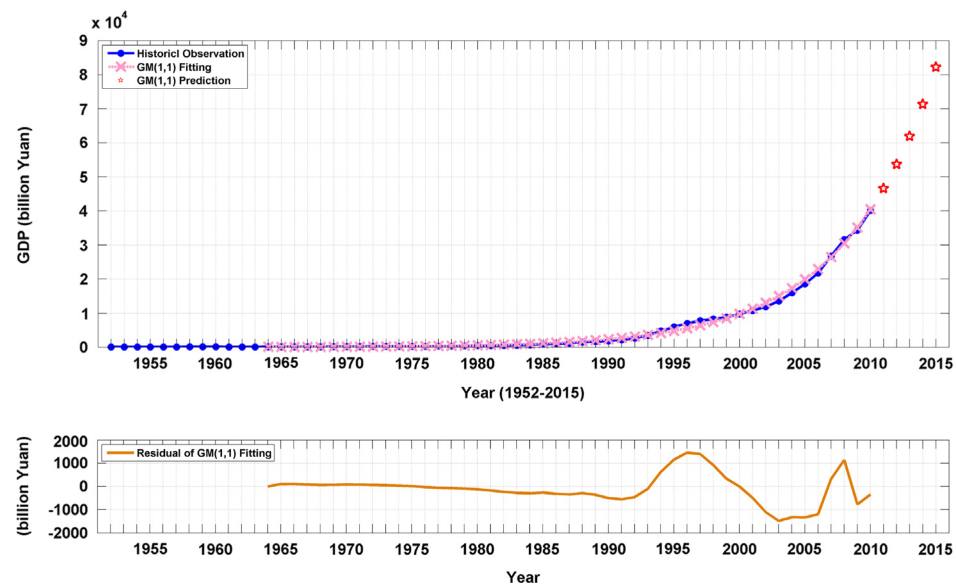

Fig. 3. The GM(1,1) prediction to the year 2015.

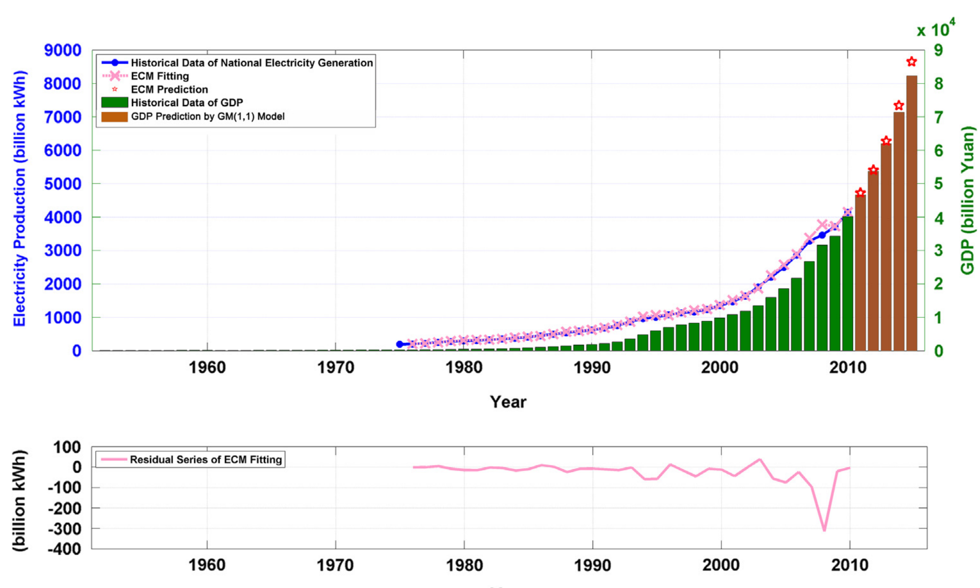

Fig. 4. The estimation of China's electricity generation to the year 2015.

2.2. Future development trend based on GM(1,1)

To analyze the electricity generation trend for the next several years, first a GM(1,1) model is applied to predict economic growth and then obtained the synchronous electricity increase using the ECM model above (Eqs. (5) and (8)). China experienced a long period of reverse social productivity, and GDP growth during this period was small. This made it difficult to apply the grey model because the one-accumulated generating operation (1-AGO) was not exponentially distributed. Therefore, the training dataset for

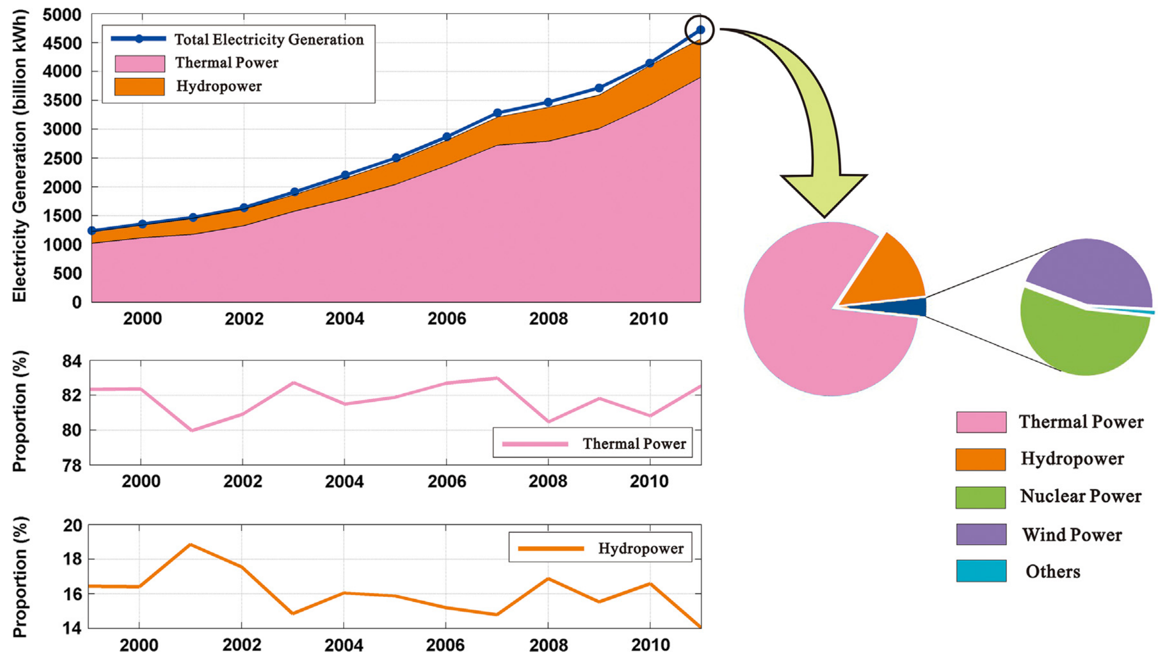

Fig. 5. China's thermal-hydro power structure.
Resource: Ref. [15].

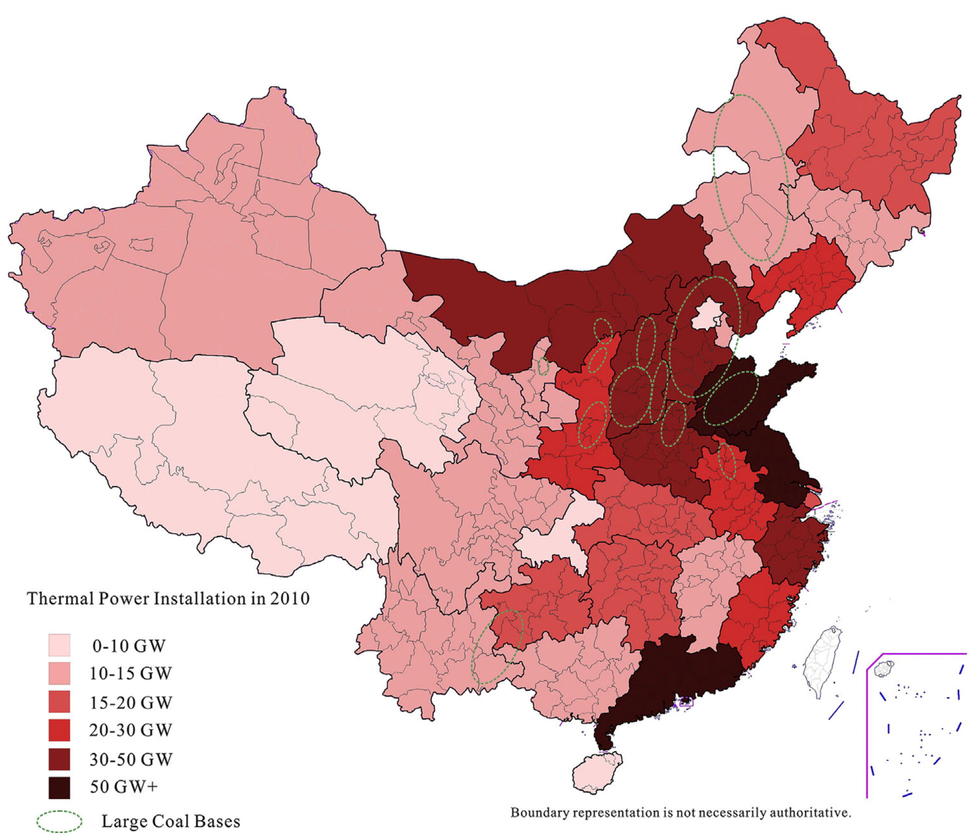

Fig. 6. Thermal power installation in 2010.
Resource: Ref. [24].

the GM(1,1) prediction was selected by minimizing the fitting error; as a result, the 1964–2010 data were chosen to predict the 2011–2015 GDP (Fig. 3).

The GM(1,1) model [20] is defined as

$$\frac{dx^{(1)}(t)}{dt}+ax^{(1)}(t)=b \tag{9}$$

where $x^{(1)}(t)$ is the one-accumulated generating operation (1-AGO) series, a and b are the grey developmental coefficient and grey control parameter, respectively. The grey derivative for the first-order grey differential equation with 1-AGO data as the intermediate information is conventionally represented as:

$$\frac{dx^{(1)}(t)}{dt}=\lim_{\Delta t\to 0}\frac{x^{(1)}(t+\Delta t)-x^{(1)}(t)}{\Delta t} \tag{10}$$

And $dx^{(1)}(t)/dt=x^{(1)}(t+1)-x^{(1)}(t)=x^{(0)}(t+1)$, when $\Delta t\to 1$ roughly.

The parameters are conventionally determined by least-squares method. The solution to Eq. (9) is:

$$\hat{x}^{(1)}(k)=(x^{(0)}(1)-b/a)e^{-a(k-1)}+b/a,\ k=2,3,\ldots \tag{11}$$

Therefore,

$$\hat{x}^{(0)}(k)=\hat{x}^{(1)}(k)-\hat{x}^{(1)}(k-1)=(x^{(0)}(1)-b/a)(1-e^{a})e^{-a(k-1)}, k=2,3,\ldots \tag{12}$$

As this Fig. 3 shows, China's GDP is predicted to reach 82,230 billion yuan by 2015. This result is consistent with reports that China's GDP will be doubled compared to its 2010 GDP [21]. That is, the grey model, based on the 1964–2010 data, is able to predict the development trend of China's GDP, at least within a near future.

As mentioned above, the ECM model (Eqs. (5) and (8)) were used to estimate electricity generation based on the GDP prediction. Fig. 4 shows that China's electricity generation will reach 8651 billion kW h by 2015. This paper will refer to this estimation

Table 5
Electricity installation and maximum electrical load in different regions of China, 2010. ***Resource***: Ref. [24].

Regional power grid	Areas contained	Electricity installation (10 MW)	Max electrical load (10 MW)	Installation/max load
North China power grid	Beijing, Tianjin, Hebei, Shanxi, Shandong, West Inner Mongolia	18,715	15,319	1.22
Northeast power grid	East Inner Mongolia, Liaoning, Jilin, Heilungkiang	6,727	4,713	1.43
Northwest power grid	Shaanxi, Gansu, Ningxia, Qinghai, Xijiang	7,585	4,055	1.87
East power grid	Shanghai, Jiangsu, Zhejiang, Anhui, Fujian	18,329	16,606	1.10
Central China power grid	Chongqing, Hubei, Hunan, Henan, Jiangxi, Sichuan	16,271	11,157	1.46
South China power grid	Guangdong, Guangxi, Yunnan, Guizhou, Hainan	13,658	10,436	1.31

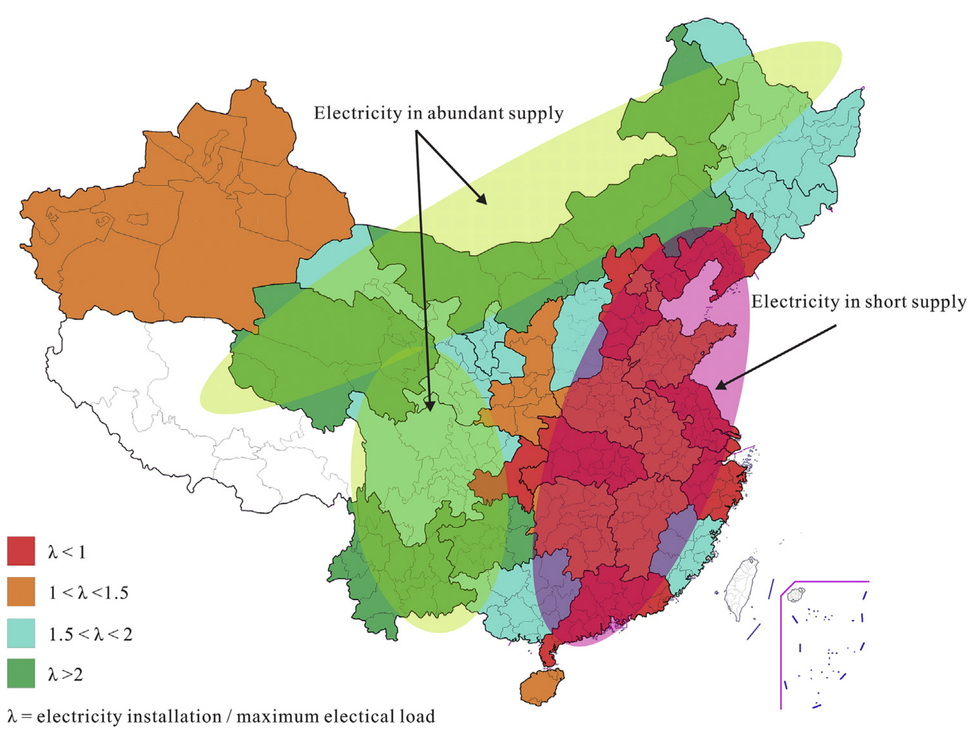

Fig. 7. Unbalanced electricity demand and supply in China.
Resource: Ref. [24].

in the following discussion of China's thermal power generation and renewable energy potentials.

2.3. Long-term thermal-hydro energy structure

China's power generation is expected to experience continued rapid growth for some time; this will be a strong driving force for the development of social productivity. In China, thermal power generation has been the main form of electricity production for many years; more than 80% of China's electricity is currently produced by thermal power (Fig. 5). For example, China's 2011 total electricity generation was 4722 billion kW h, with a year-on-year increase of 11.68%; at the same time, thermal power generation reached 3898 billion kW h, accounting for 82.54% of the total power generation [4]. However, hydropower is also important for electricity generation in China and makes up approximately 14–18% of the total power generation (Fig. 5). As Fig. 5 shows, the proportions of thermal power and hydropower show a negative correlation. When thermal power accounted for a low proportion of electricity, such as in 2001, more electricity was provided by hydropower. This is the thermal-hydro complement structure used in China.

With such a high proportion of thermal power generation, the heavily coal-based energy structure in China increases the need for coal production as well as environmental protection. In 2011, 1.35 billion tons of coal (48.31% of total coal production) were used for power generation [15]. Although China has abundant coal reserves, they are not evenly distributed throughout the country. Most are centrally located in Shanxi, Inner Mongolia, Shaanxi, and Xinjiang provinces. However, eastern China and the southeast coastal areas are the regions with the most active economic development; thus, they require a large quantity of coal and electricity. Unfortunately, these areas are located far from the coal-rich regions, which causes problems for both mining and long-distance transport (Fig. 6).

Thermal power will remain the leading form of power generation in China for the foreseeable future. According to the 12th FYP, the government will give priority to the development of thermal power generation and will speed up the construction of coal-rich bases in the West. They plan to construct 14 coal bases during this period [22]. However, toxic gases emitted from thermal power generation result in serious environmental pollution, mainly due to coal combustion. Despite the reliance on thermal power, coal consumption for thermal power generation is projected to decline to 325 g of standard coal per kW h by the year 2015. Already, consumption has decreased by 8 g of standard coal per kW h in 2010 [23].

2.4. Unbalanced electricity demand and supply in China

As mentioned above, the distribution of China's energy resources is unbalanced. Western China has rich energy resources, especially wind and solar energy resources. In recent years, electricity installation in the west has shown a continuous and sharp increase. However, western China is economically undeveloped; the underdevelopment of social industry and scientific techniques has limited electricity generation and consumption. In contrast, the eastern regions and southeast coast of China are relatively developed, but electricity supply in these areas is affected by a shortage of energy resources.

Table 5 and Fig. 7 show the unbalanced electricity demand and supply in China in 2010 [24]. The northeast and northwest power

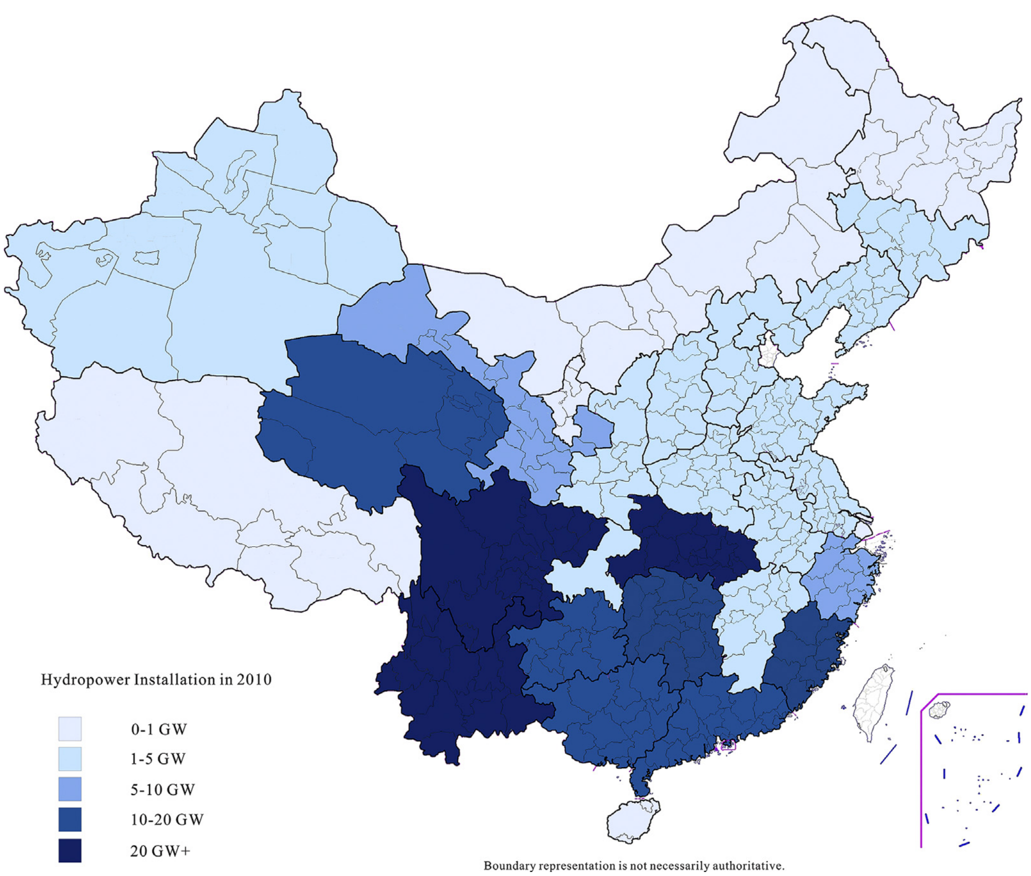

Fig. 8. Hydropower installation in 2010.
Resource: Ref. [24].

grids have an abundant supply of electricity, while the eastern and northern China power grids create heavy burdens on their limited power supply. One way to evaluate a region's electricity needs is by calculating its electricity sufficiency (ES):

$$\text{electricity sufficiency} = \frac{\text{electricity installation}}{\text{max electricity load}}. \tag{13}$$

As Table 5 shows, Shanghai, located on the eastern coast, has the smallest ES value, just below Zhejiang, Jiangsu, Guangdong, and Hebei, which are also on the eastern coast. Clearly, trans-regional and trans-provincial resource allocations are needed to maintain balance between electricity demand and supply in different areas.

3. Renewable energy in China

In the 21st century, countries throughout the world – especially developing nations – face the dual pressures of environmental protection and economic growth. Thus, renewable energy utilization should be adopted, with the goal of maintaining sustainable development and creating a better ecological environment [25]. As a low-carbon society becomes a new goal worldwide, renewable energy will play a central role in the future [26]. Unquestionably, renewable energy possesses huge potential, but how quickly its benefits can meet the growth of global energy demand hinges on government support to make renewable energy cost-competitive in energy markets.

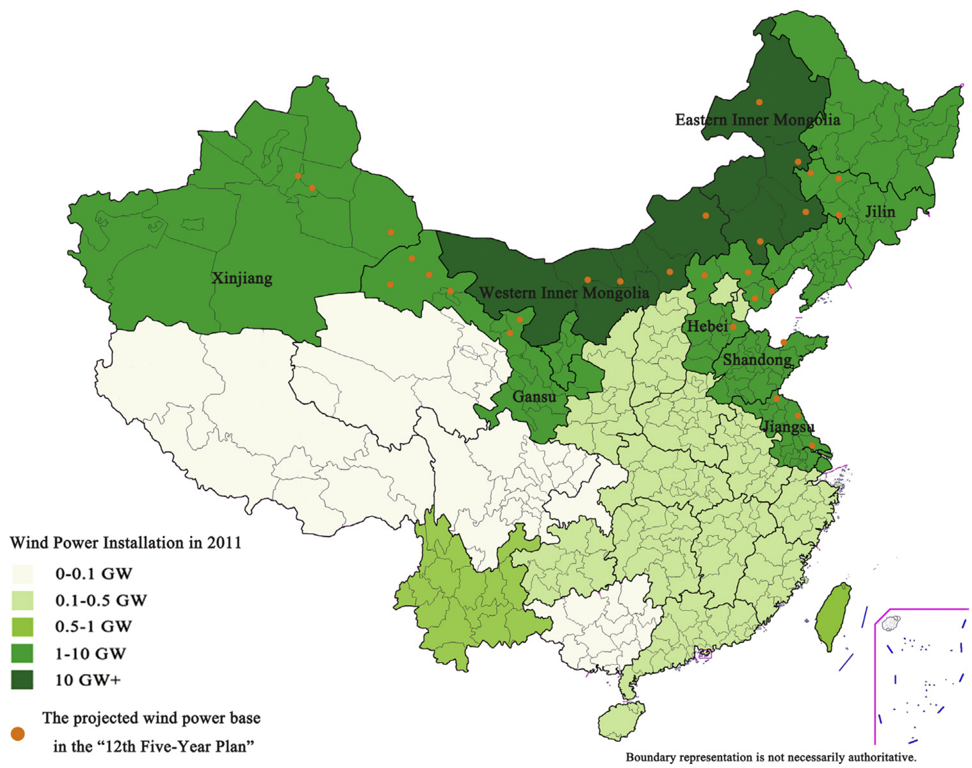

Fig. 9. Wind power installation in 2011 and the development trend projected in the 12th FYP.
Resources: Refs. [30,31].

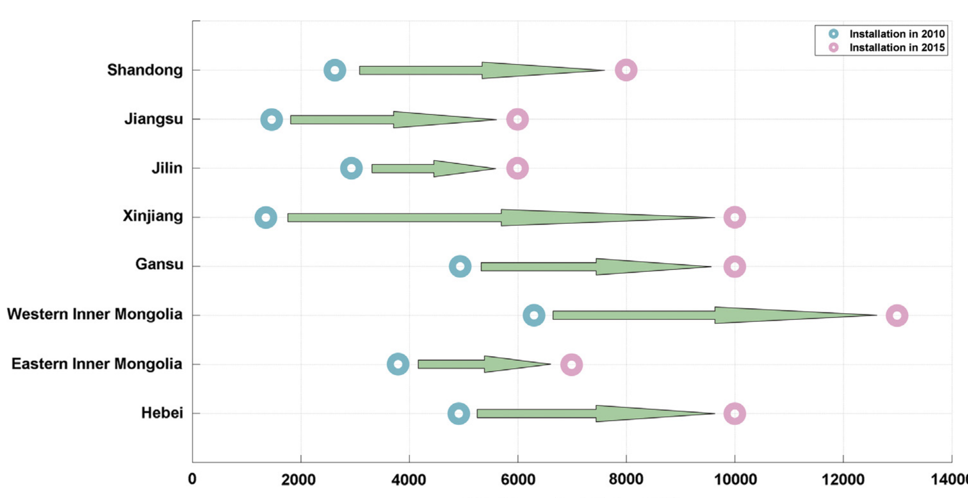

Fig. 10. Eight provinces with large-scale wind power bases projected in the 12th FYP.
Resources: Ref. [31].

3.1. Renewable power development in the 12th FYP

In its 12th FYP, the Chinese government encourages the development of renewable power generation, especially hydropower, wind power and photovoltaic (PV) power.

3.1.1. Hydropower

Although hydropower accounts for only a limited proportion of total power generation in China, it plays a significant role in the power structure. Hydropower is important for Electric Peak shaving, which guarantees the grid's security and economical operation. As with other energy resources, water resources have an unbalanced distribution; approximately 70% of total water resources are found in the southwest (Fig. 8) [8].

In the past few years, development of hydropower in China has been stable, benefiting from its technological maturity and economical costs. In the 12th FYP, the government proposed increasing the construction of hydropower installations, mainly in the Jinsha Jiang, Lancang, Tadu, and Yalong rivers as well as the upper reaches of Yellow River and the middle reaches of the Yarlung Zangbo River [27]. By the end of 2015, China's hydropower installation is projected to reach 2.9×10^5 MW, with an added capacity of 6.1×10^4 MW [28].

3.1.2. Wind power

Wind power is one of the most promising new energy resources in China because there are rich resources that can be developed quickly. From 2006 to 2009, wind power in China experienced four years of consecutive growth—more than 100% per year [29]. By the end of 2011, the national total wind power capacity was 62364.2 MW, with a growth rate of 39.4% [30]. Fig. 9 shows China's wind power installation in 2011: Inner Mongolia is the leader, with a total capacity of 17594.4 MW, followed by Hebei, Gansu, and Liaoning [30]. However, despite tremendous increases in wind power, it still provides less than 1% of the national electricity supply [15].

Wind energy resources are found in the three northern areas—northeast, northwest, and northern China. By the end of 2015, China's wind power installation is projected to reach 10^5 MW, and the annual power generation from wind power is projected to be 2×10^{11} kW h [31]. The 12th FYP emphasizes wind power development in several ways:

- Construction of large-scale wind power bases in the three northern and eastern coastal areas. Eight large-scale wind power bases are projected to be constructed in Hebei, eastern Inner Mongolia, western Inner Mongolia, Jilin, Gansu, Xinjiang, Jiangsu, and Shandong (Figs. 9 and 10). By the end of 2015, the total installation of provinces with large-scale wind power bases is projected to be more than 7×10^4 MW [31].
- Acceleration of the construction of medium and small-sized wind power programs in areas relatively rich in wind energy. By 2015, wind power installation in these areas is planned to produce 3×10^4 MW [31].
- Promotion of offshore wind power. In the next few years, the key regions for offshore wind power development will be Hebei, Jiangsu, and Shandong provinces.
- Encouragement for the development of decentralized wind power.

Although wind power in China is promising, the main obstacles to the development of a wind power industry are grid connection and power transmissions. Due to the delayed development of grid operations and construction, the rate of wind power abandonment in the three northern areas reached 16% in 2011, representing an economic loss of 6.6 billion yuan [32].

3.1.3. PV power

As one of the most active emerging industries in China, PV power generation has shown a booming development trend over

Table 6
Electricity installation and the environmental benefits from renewable energies.

		Thermal	Hydro	Wind	PV	Total
2011	Installation (MW)	765,460 [a]	230,510 [a]	62,364 [b]	2890 [c]	1061,334
	Annual growth rate of installation (%)	7.86%	6.69%	39.4%	233.33%	
	Rate of grid connection (%)			72.15% [d]	73.4% [c]	
	Proportion (%)	72.5% [a]	21.83% [a]	4.26%	0.20%	100%
	Annual utilization hours (h)	5294 [a]	3028 [a]	1903 [a]	1700 [e]	
	Growth of utilization hours (h)	264 [a]	−376 [a]	−144 [a]		
	Power generation (billion kW h)	3,897.5 [a]	662.6 [a]	73.2 [a]	0.91 [f]	4721.7 [a]
	Proportion of power generation (%)	82.54% [a]	14.03% [a]	1.55%	0.02%	
	Annual growth rate of power generation (%)	14.07% [a]	−3.52% [a]	48.16% [a]	760% [f]	11.68%
	Equivalent to standard coal (t)	1.29×10^9	2.19×10^8	2.42×10^7	3.00×10^5	
	Reduction of CO_2 (t)	–	5.69×10^8	6.29×10^7	7.80×10^5	
	Reduction of SO_2 (t)	–	5.26×10^6	5.81×10^5	7.20×10^3	
	Reduction of NO_x (t)	–	1.53×10^6	1.69×10^5	2.10×10^3	
2015	Installation (MW)	928,000 [f]	290,000 [g]	100,000 [g]	21,000 [g]	1463,000 [h]
	Proportion (%)	63.43%	19.82%	6.84%	1.44%	100%
	Annual growth rate of installation 2011–2015 (%)	4.93%	5.91%	12.53%	64.18%	
	Power generation (billion kW h)		910 [g]	190 [g]	25 [g]	8651
	Equivalent to standard coal (t)		3.00×10^8	6.27×10^7	8.25×10^6	
	Reduction of CO_2 (t)	–	7.80×10^8	1.63×10^8	2.15×10^7	
	Reduction of SO_2 (t)	–	7.20×10^6	1.50×10^6	1.98×10^5	
	Reduction of NO_x (t)	–	2.10×10^6	4.39×10^5	5.78×10^4	

[a] *Resource*: Ref. [40].
[b] *Resource*: Ref. [43].
[c] *Resource*: Ref. [44].
[d] *Resource*: Ref. [45].
[e] *Resource*: Ref. [46].
[f] *Resource*: Ref. [47].
[g] *Resource*: Ref. [48].
[h] *Resource*: Ref. [35].

the past few years. In 2011, China's PV power installation reached 3000 MW, which represents more than 200% growth from the 900 MW installation in 2010 [33]. Although the growth rate is encouraging, PV power is only a small proportion of China's power structure (Fig. 6).

Solar energy is most abundant in Qinghai-Tibet Plateau, northern Gansu, northern Ningxia, and southern Xinjiang provinces. With more than 3200 h of annual sunshine, the annual radiation in these areas exceeds 6700 MJ/m^2. The 12th FYP projects construction of several PV power bases in these solar-rich areas, mainly in Gansu, Qinghai, and Tibet. By the end of 2015, China's PV power installation is projected to be 21,000 MW [34].

As an ideal area for PV power generation, Jiuquan will become the biggest PV power base in Gansu Province. Currently, Jiunquan's PV power installation represents two-thirds of Gansu's total PV power [27] and is projected to reach 2×10^3 MW by 2015 [35]. Dunhuang, a region with rich solar energy resources, also shows strong potential. Its PV power installation is projected to reach 621 MW in the end of 2012 [36]. Qinghai Province is also projected to have one of the PV power bases in China. Annual solar radiation there is 5800–7400 MJ/m^2. By the end of 2015, the PV power installation in Qinghai will reach 4000 MW [37]. Finally, Tibet is one of the richest regions for solar energy in the world. From 2011 to 2015, the PV power and solar thermal power installation in Tibet is projected to be 220 MW, providing 11.5% of China's total power supply [38].

3.2. Benefits from renewable power generation

Renewable power generation reduces the use of fossil fuels and their emissions. Table 6 shows the electricity installation and the benefits from renewable energies in 2011 and 2015.

In 2011, China's total power installation was 1.056 billion kW, with 27.5% coming from renewable power installation [4,39]. However, due to the limitation of utilization hours, renewable power generation only made up 17.46% of the total power generation. That is, 82.54% of the total power generation was still from thermal power. According to the China Electricity Council (CEC), the coal consumption for thermal power generation in 2011 was 330 g of standard coal per kW h [40]. Thus, 1.29 billion tons of standard coal was consumed by thermal power generation; this is equivalent to emissions of 3.35×10^9 t of CO_2, 3.10×10^7 t of SO_2, and 9.03×10^6 t of NO_x.

The CEC estimates that the national total power installation will be 1.463 billion kW in 2015 [41]. They have set goals of reducing SO_2 and NO_x emissions from thermal power generation to 8×10^6 t and 7.5×10^6 t, respectively, by 2015; these are decreases of 16% and 29%, respectively, compared to 2010 levels [42]. The CEC hopes to meet these goals by encouraging the development of renewable energy generation, especially wind and PV power.

4. Impacts on policy

The rapid development of China's renewable power generation requires strong government finance and policy support. The 12th FYP suggests several areas of focus.

4.1. Encourage the development of renewable energy

Renewable and sustainable energy usage is now the global development trend of the power industry. Due to their abundant energy resources, wind and PV power industries hold the most promise for renewable power generation in China. In addition, the 12th FYP offers the following policy suggestions to encourage the development of renewable energy during its 2011–2015 effective period.

- Increase the percentage of renewable energy in the nation's total energy consumption. Annual renewable power generation is expected to reach 478 million tons of standard coal by 2015 [49]. Renewable energy is expected to make up over 9.5% of the total energy consumption [49].
- Develop renewable energy generation as an important power source in the nationwide power system. Renewable installations are projected to provide 1.6×10^7 MW [49] during this period, and renewable power generation is projected to make up 20% of the total power generation by 2015 [49].
- Work towards the goal of expanding the use of solar thermo-application, promoting the direct use of medium-low temperature geothermal power, advancing heat pump technology applications, spreading the use of biomass briquettes and biomass cogeneration, and speeding up the development of biogas and other types of biomass gases.

4.2. Develop advanced techniques related to renewable power generation

Due to the variability of renewable power output, efforts should be made to maintain grid stability and to ensure grid security when large-scale renewable power sources are connected. Effective use of renewable energy requires technologies to predict the amount of energy produced, to safely integrate the renewable power connection into the grid, and to regulate power management and grid operation.

- For wind power generation, large scale and high efficiency are the two main directions of development. Critical goals in the 12th FYP period are connecting large-scale wind power output to the grid, increasing resource assessment and improving monitoring techniques for large wind farms, and using large land wind turbines with a capacity of 6–10 MW [50].
- For solar power generation, the integration of collecting, storing, and using the power is the prospective trend. Critical goals in the 12th FYP period are creating large-scale PV power systems, promoting large-scale solar–thermal power generation, providing high power inverters to connect PV power to the grid, and increasing production of solar cells and critical equipment for PV power generation.
- Technologies capable of storing and integrating intermittent power supplies are necessary for connecting large-scale, wind- and solar-generated power to the grid.

4.3. Expediting the construction of electricity infrastructure

Along with the fast growth of renewable installation, power transportation is facing enormous pressure. It is necessary to expedite the construction of electricity infrastructure.

- Due to the unbalanced distribution of renewable energy resources, long-distance transmission of electricity also requires advanced, large-capacity transmission lines. The 12th FYP proposes expediting the construction of intra- and interprovincial transmission lines and the construction of a trans-regional ultra-high-voltage (UHV) DC grid (Fig. 11). Trans-provincial and trans-regional power transmissions make nationwide combined thermal-renewable power scheduling possible.
- Smart grid construction is also emphasized in the 12th FYP. Such grids must support distributed power access, centralized/decentralized

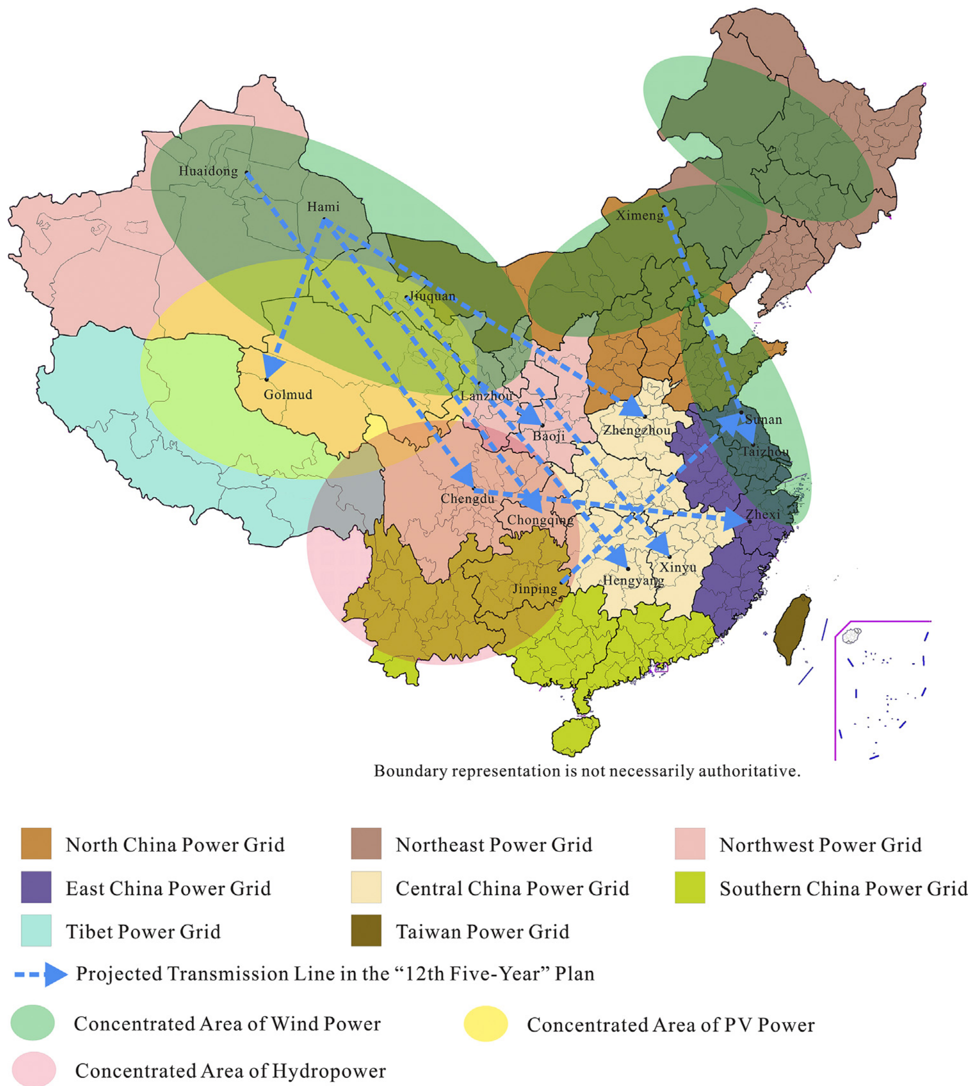

Fig. 11. The projected trans-provincial and trans-regional transmission lines in the 12th FYP.

energy storage, intelligent transmission, distribution equipment, and interactive platforms for user management and information.

4.4. Develop large-scale multi-energy complementary power systems

Under the ongoing energy revolution, renewable energies are likely to have a significant share in the future power sector. In this case, combined renewable-thermal scheduling is more effective than traditional hydro-thermal scheduling. The 12th FYP makes several suggestions in this regard.

- Design an autonomous running system and a new-type inverter for multi-energy complementary power generation. Develop technologies for energy storage control, energy stability control, and energy management.
- Develop a distributed energy supply technology that is multi-energy complementary. The combined efficiency of a distributed multi-energy complementary system is expected to be higher than 85% [50].
- Construct demonstration projects of a grid-connected complementary power system. This includes a 100 MW demonstration project of a wind/solar/storage complementary system and a 10 MW demonstration project of a hydro/solar/storage complementary system [50].

5. Further discussion

Being the most promising alternative energy resource, renewable energy not only has huge potential but also offers irreplaceable advantages of resource utilization. As China's renewable industry is experiencing a booming expansion, all eyes are fixed on the utilization efficiency of renewable energy conversion and the sustainable development of future power generation. The healthy development of China's future power structure is facing both opportunities and challenges.

5.1. Discussion on China's current electricity generation

Renewable power generation shows its strong advantage in China, mainly due to a huge resource potential and the benefits of emission reduction. While under the current situation of power generation, thermal power will still be the main form of China's power generation in the foreseeable future.

- A remarkable equilibrium relationship between China's GDP and electricity generation can be found, as discussed in Section 2. This continued high economic growth requires the strong support of the electricity industry. With national economic increases, shortages of electricity supply have emerged and have become more serious in recent years. This promotes the rapid growth of national power demand.
- Under the situation of growing power demand, renewable and sustainable energy usage is now the focused development trend of China's power industry. Renewable energy in China has a huge resource potential. The maturing technologies of both renewable utilization and power transportation make it possible to share a larger proportion of renewable power generation and to optimize the energy source composition in future power structure.
- The major limitations of renewable generation are grid integration and power transmission. Different from fossil fuels, power generation based on renewable energy is not from a persistent and constant supply. When large-scale penetration of intermittent renewable power is integrated into a grid, the electricity system may become variable. How to make the renewable energy predictable and controllable becomes one of the most focused issues according to renewable power generation.
- Although renewable power generation in China shows bright prospects, thermal power will still be the main form of power generation in China for the foreseeable future. In China's national power structure, the installation of thermal power shares a proportion larger than 75%. Because of the shorter time construction period of thermal power plants, with the large development of the national economy, the proportion of thermal power in the power structure is not decreased. This brings a heavy burden on China's coal supply and emission reduction.
- Construction of a power grid instrument in China is difficult due to pace of the rapid growth of the national electricity demand. The main investment destination of the electricity industry is mainly in the expansion of power installations. Investment of grid instrument construction is relatively insufficient. As a consequence, power blackouts are often caused by the outages of the weak structure of power system.

5.2. Suggestions for China's future energy development

China's future power structure needs a healthy and balance development between thermal power and renewable power generation. The development is facing both opportunities and challenges.

- On the premise that thermal power is regarded as the long-term main power supply, it is urgently needed to further reduce the coal consumption and corresponding emissions.
- Under the over-capacity of national thermal power construction, the government should take steps to reduce the proportion of thermal power. Construction projects should focus on large, efficient, and clean coal-fired units, instead of small units.
- Steps should be taken to optimize the structure of the power distribution grid and to reduce the loss of power transportation. Moreover, it is urgent to enhance the anti-disaster ability of the power grid system.
- Renewable power could meet some of the demand for more electricity with lower emissions. Development of renewable power generation should be further encouraged and supported to approach a clean and sustainable power structure.
- Critical techniques are urgently required for renewable power development, such as a prediction technique for renewable power generation, integration technique for renewable power connection, and dispatching technique for power management and grid operation. Efforts should focus on the development of advanced alternative power techniques.

6. Conclusions

China has depended on a coal-based power supply for many years, which has resulted in a heavy burden of coal production and serious environmental deterioration. This paper first analyzes the relationship between China's economic production and electricity generation, using the Johansen co-integration test and the ECM. The results show that there is a positively related, long-term equilibrium relationship between China's GDP and its electricity production. The continued high economic growth requires the strong support of the electricity industry. Estimations show that China's electricity generation will reach 8651 billion kW h by 2015.

A sharp increase of power demand is required in the foreseeable future, but the fossil fuel power generation cannot meet both the power demand growth and the emission reduction target. In recent years, China's renewable power generation has shown a booming developmental trend, especially for wind and PV power. This paper overviews the exploitation potential, current status and future developmental trend of China's renewable power generation. Due to the unbalanced distribution of China's energy resources, the combined dispatching of a centralized renewable-thermal grid operation is discussed, including trans-provincial and trans-regional power transmissions. The excellent grid operation will provide strong support for China's renewable power generation and sustainable energy utilization. In the next few years, the government is expected to show great interest in encouraging the development of new power generation and related techniques and infrastructure. The government should also take steps to achieve a clean and sustainable power structure.

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